United States
Department of
Agriculture

Forest Service

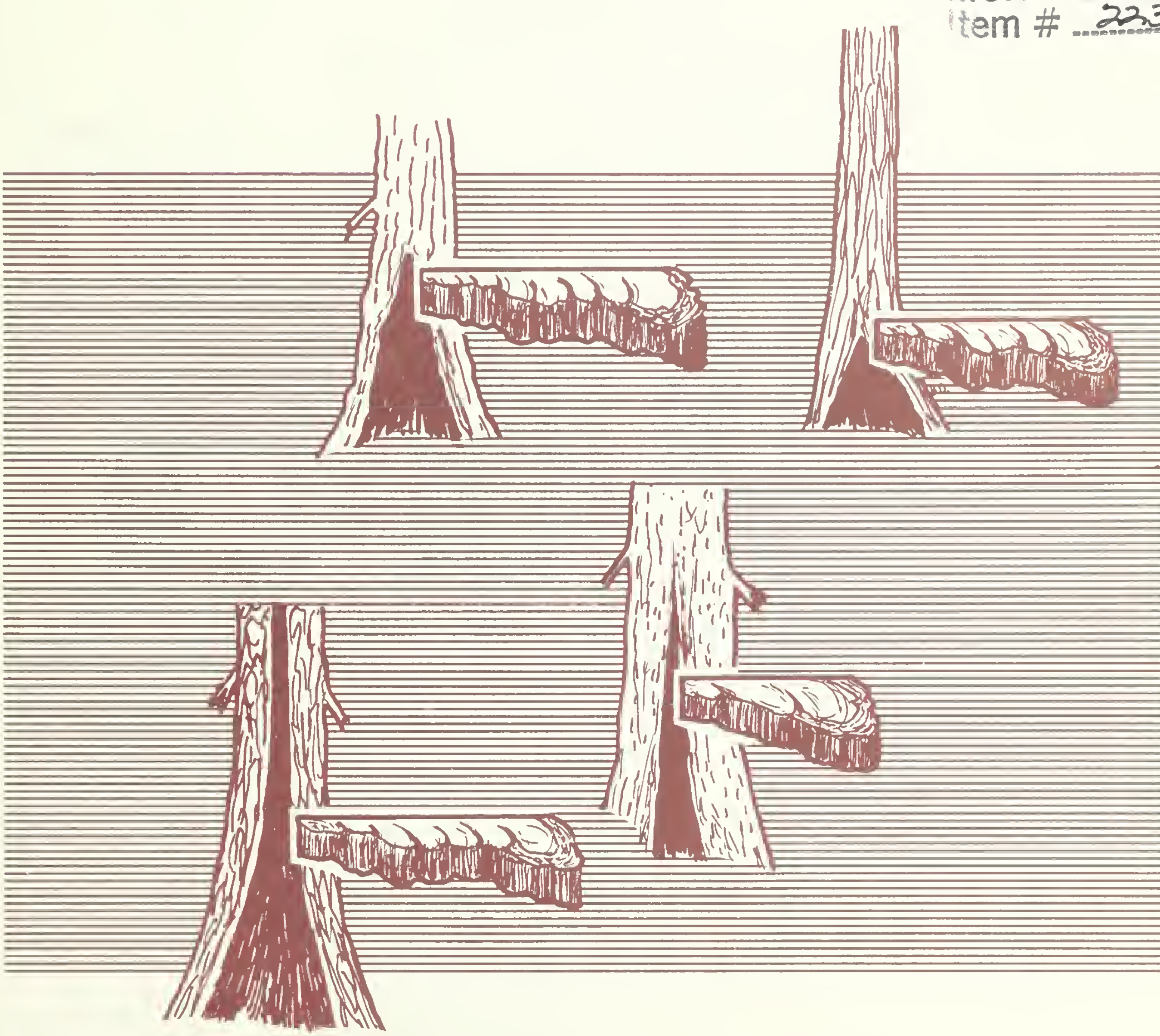
**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Paper
INT-301

January 1983

Variation in Estimates of Fire Intervals: A Closer Look at Fire History on the Bitterroot National Forest

Stephen F. Arno and Terry D. Petersen



THE AUTHORS

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RESEARCH SUMMARY

Variations in estimates of intervals between wildfires (occurring between the years 1600 and 1910) are examined in relation to the size of fire history sample units. This comparison is based on re-analysis of data from an earlier study, including 904 fire scars from 172 trees on three study areas on the Bitterroot National Forest, Mont. Fire history evidence is examined within sample units of five sizes, ranging from a point on the ground (records from a single tree) to those contained on all sample trees in a large stand (200 to 800 acres; 80 to 320 hectares).

Mean fire intervals are compared for each size class of sample units within each of five forest zones for the three study areas. Mean fire intervals for larger units are shortest because they designate the occurrence of fire somewhere within the unit. Mean fire intervals are generally longest for the point on the ground (or single tree), but such intervals are often incomplete because light fires often failed to scar individual trees in their path. Also, in areas having long fire intervals it is difficult to reconstruct intervals from a single tree because at least two fire scars are necessary. Therefore, construction of a master fire chronology based on records from several trees is generally advantageous.

The authors recommend basing calculations of fire intervals on small- to medium-sized sample units—between 1 and 100 acres (0.4 and 40 hectares) depending upon the type of forest studied. They also stress the importance of interpreting the size of sample units when comparing fire intervals from different studies.

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INTRODUCTION

Anyone who has studied fire history over a sizeable area of land has faced the problem of reporting findings in terms that will be most meaningful for land managers and scientists. Researchers have commonly reported the mean **fire interval** (interval between fires) during the 250- or 300-year period before fire suppression began in the early 1900's. Mean fire intervals can be calculated for a continuum of stand sizes, however, ranging from entire watersheds to single points (individual trees).

The mean fire interval for a large area is often calculated by combining all fire years that have been identified at sample points (individual fire-scarred trees) within it into a master fire chronology covering the entire area. (Fire history terminology used here is based on Romme 1980). Mean fire intervals calculated from a master fire chronology probably tend to be shortened as the study area becomes larger and more sample trees (points) are included. This reduction of fire intervals with increasingly large sample areas would result primarily because many fires burned only small portions of the area. Thus when such fires (fire years) are incorporated into a master fire chronology, it must be remembered that the data (including mean fire intervals) represent only the occurrences of fire somewhere within the sample area. Another problem with calculating mean fire intervals for large areas is that such areas often include several different habitats that have different fire histories. A fire-interval statistic based on large areas, therefore, is of limited use for characterizing the fire history in smaller stands.

Conversely, estimates based on fire scars from a single tree can be expected to overestimate the length of mean fire intervals. This occurs because light surface fires often fail to inflict a new wound even on previously scarred trees (Houston 1973; Arno 1976; Dieterich 1980). On the other hand, records from a single tree might include scars from tiny spot fires having little ecological significance. The opportunity to accept only evidence of spreading fires, represented by fire scar dates occurring on two or more sample trees in a stand, is not available when calculations are based on an individual tree.

With these considerations in mind, several authors (for example, Tande 1979; Arno 1980; Dieterich 1980; Barrett 1980; Davis 1980) have reported fire intervals for small areas, each representing a relatively homogeneous site and stand. This approach relies on the combined fire-scar records from two or more sample trees as well as ages of fire-initiated tree regeneration (such as distinct age-classes of shade-intolerant species requiring fire for establishment) from the same location. But, how large of an area should be sampled to provide the most useful characterization of fire history?

The following re-analysis of fire history data from the Bitterroot National Forest has been made to help address this question by illustrating the effect of size of sample units on length of fire intervals. A concurrent goal of this analysis was to provide more refined fire history data for use in that area.

METHODS

Fire scars on trees and fire-initiated tree regeneration (age-classes) were sampled on three study areas (Onehorse, Tolan, and West Fork) on the Bitterroot National Forest in western Montana (fig. 1). These data were used as the basis for a previous report (Arno 1976), which presented fire intervals only for relatively large stands, generally 100 to 800 acres (40 to 320 hectares) in size.

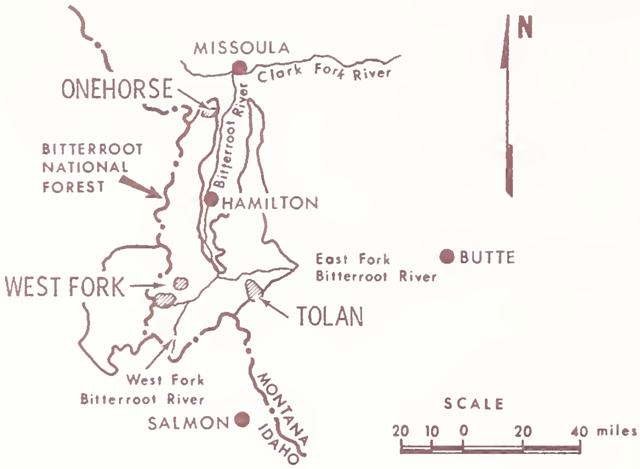

Figure 1.—Location of the three study areas.

More recently, it was reasoned that this data base (including 904 individual fire scars from 172 trees plus age-class information) could be inspected to observe the effect of sample-area size on length of fire intervals. For the current study, we inspected the topographic maps showing sample tree locations for all three study areas and designated sample units of five sizes. We superimposed these sizes of sample units on the maps so as to efficiently include all concentrations of sample trees occupying similar topographic positions and habitat types. Thus, to the extent that the distribution of sampled trees and topography allowed, we designated sample units of the following sizes within a given forest zone:

Large stand	=	200 to 800 acres (80 to 320 ha)
Small stand	=	50 to 100 acres (20 to 40 ha)
Grove	=	10 to 15 acres (4 to 6 ha)
Cluster	=	about 1 acre (about ½ ha)
Single tree	=	point on the ground.

We included the maximum number of sample trees in units of any given size, as if we were carrying out new field studies and were seeking the most complete fire history information obtainable within each size class of sample unit (fig. 2, A and B).

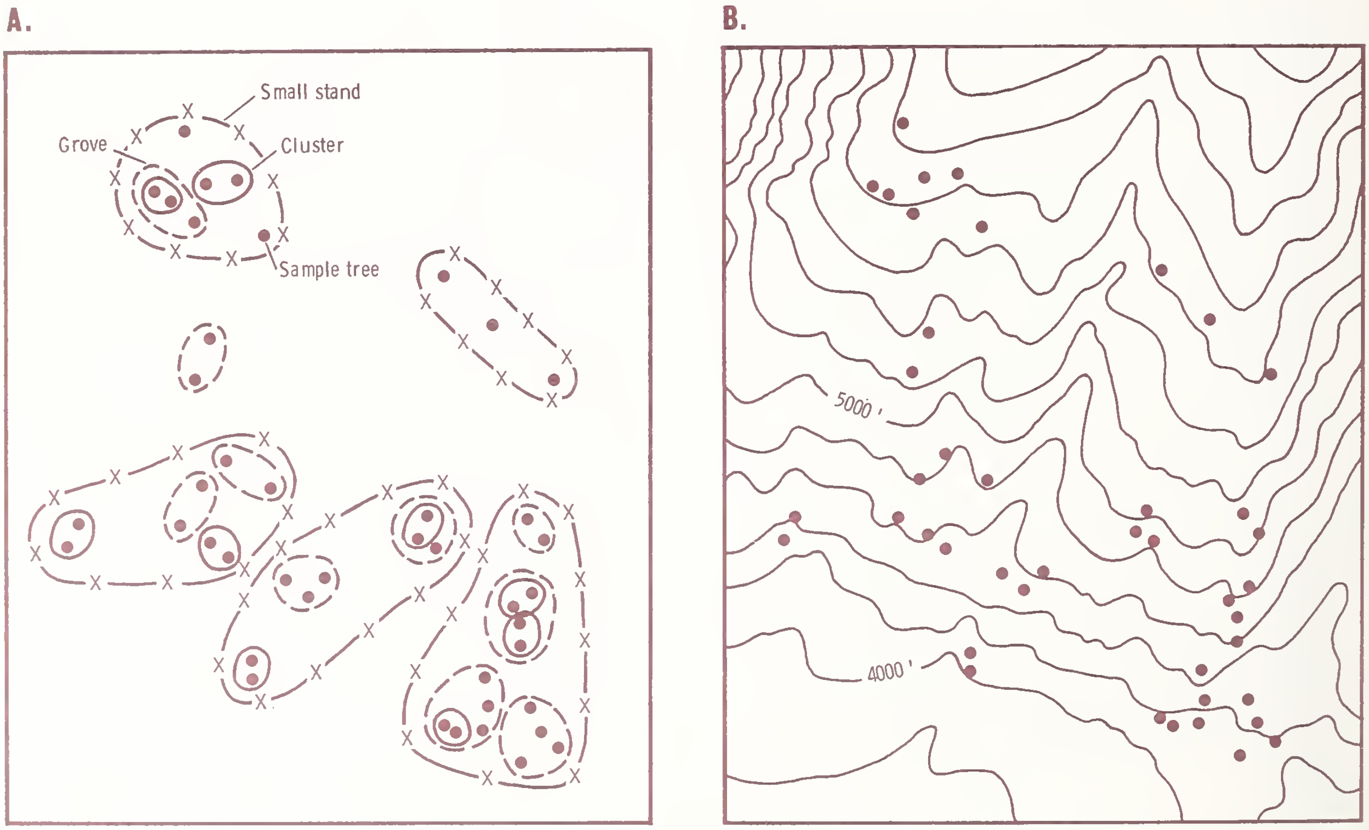

Figure 2.—A. Location and arrangement of sample units and sample trees within the large stand in the montane zone at the Onehorse study area. B. Topographic map of same area showing sample trees.

The following forest zones were used for stratifying results (representative habitat types for each zone are listed in table 1):

1. Valley edge—the lowest slopes (3,800 to 4,800 ft; 1 160 to 1 460 m elevation), predominantly ponderosa pine (*Pinus ponderosa*) forest.
2. Montane slopes— lower to midelevation forests (4,200 to 6,200 ft; 1 280 to 1 890 m) of seral ponderosa pine and potential-climax Douglas-fir (*Pseudotsuga menziesii*).
3. Moist canyon—a moist variant of montane slopes, primarily with seral western larch (*Larix occidentalis*) and potential-climax grand fir (*Abies grandis*).
4. Lower subalpine—midelevation forests (6,000 to 7,500 ft; 1 830 to 2 290 m) primarily of seral lodgepole pine (*Pinus contorta*) and potential-climax subalpine fir (*Abies lasiocarpa*).
5. Upper subalpine—high elevation forests (7,500 to 8,600 ft; 2 290 to 2 620 m) primarily of whitebark pine (*Pinus albicaulis*) and potential-climax subalpine fir (*Abies lasiocarpa*).

Mean fire intervals were then calculated by forest zone based on the cumulative fire history records within sample units of each size. This mean fire interval is an estimate of the average number of years between fires (other than tiny spot fires, not

Table 1.—Fire intervals for the period 1735 to 1900 on the three study areas in the Bitterroot National Forest, Mont. These intervals, from Arno (1976), are based on all fire years identified within 200- to 800-acre habitat type units (stands).

Habitat type groups (potential climax) (Pfister and others, 1977)	Descriptive location	General elevations	Dominant trees with continued fire exclusion (most abundant tree first)	Dominant overstory before 1900 (most abundant tree first)	Onehorse		Tolan		West Fork	
					No. of stands (No. of trees)	Mean fire interval (min-max interval)	No. of stands (No. of trees)	Mean fire interval (min-max interval)	No. of stands (No. of trees)	Mean fire interval (min-max interval)
		Feet				*Years*		*Years*		*Years*
1. *Pinus ponderosa/Festuca idahoensis* *Pseudotsuga menziesii/Agropyron spicatum* *Pseudotsuga/Calamagrostis, P. ponderosa* phase	Valley edge	3,800-5,000	Douglas-fir ponderosa pine	ponderosa pine	1 (11)	6 (2-20)	1 (4)	11 (2-18)	1 (7)	10 (2-18)
2. *Pseudotsuga/Physocarpus malvaceus* *Pseudotsuga/Calamagrostis* (except *Calamagrostis* phase) *Pseudotsuga/Symphoricarpos albus* *Pseudotsuga/Vaccinium globulare* (except *Xerophyllum* phase)	Montane slopes	4,200-6,200	Douglas-fir	ponderosa pine Douglas-fir lodgepole pine western larch	3 (46)	7 (2-28)	3 (11)	16 (4-29)	4 (23)	19 (2-48)
3. *Abies grandis* habitat types	Moist canyon	4,300-4,700	grand fir	western larch lodgepole pine Douglas-fir	1 (7)	17 (3-32)	—	—	—	—
4. *Pseudotsuga/Calamagrostis, Calamagrostis* phase *Pseudotsuga/Vaccinium globulare, Xerophyllum* phase *Abies lasiocarpa/Xerophyllum tenax* *Abies lasiocarpa/Menziesia ferruginea* *Abies lasiocarpa/Linnaea borealis*	Lower subalpine slopes	6,700-7,500	subalpine fir	lodgepole pine Douglas-fir	1 (9)	17 (3-33)	3 (16)	27 (5-62)	3 (13)	28 (5-67)
5. *Abies lasiocarpa/Luzula hitchcockii* *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* *Pinus albicaulis-Abies lasiocarpa*	Upper subalpine slopes	7,500-8,600	subalpine fir whitebark pine	whitebark pine lodgepole pine	1 (3)	41 (8-50)	2 (14)	30 (4-78)	2 (14)	33 (2-68)

scarring any other sample trees in the forest zone) occurring within, but not necessarily spreading throughout a given sample unit. These data were actually the **grand means**, or mean of the mean fire intervals, for all units of a given size. Single-tree estimates were based on the tree in every cluster having the most complete fire-scar records—namely, the shortest mean interval between fire scars. The mean of the mean (grand mean) fire intervals for all of these single trees in a forest zone was calculated. In a few instances, age-class data from intolerant trees provided evidence of an additional (earlier) fire not detected by fire scars. Such evidence was added to the fire record for all units (except single tree) in which that age class was detected.

The following approach was used to lengthen the period of record which serves as the basis for estimating mean, median, and maximum fire intervals. Arno (1976) used the period 1735 to 1900 because detailed records were available for all trees during that time, and in about 1910 fire suppression activities were begun. This relatively short period was used for that report largely to hold the time period constant for comparison of all study-area units. Inspection of the earliest fire scar records—going back to about the year 1500 at Onehorse and 1600 at Tolan and West Fork—however, showed no marked change in the frequency of fire other than that attributable to diminishing numbers of fire-recording trees (see Arno 1976, table A-4 and figure 2). Thus, in order to utilize the longest pre-fire suppression record of fire history for each stand, we counted all fire intervals, starting with the earliest recorded fire in each unit and extending to the last fire prior to 1910. The rationale for this sort of "floating" beginning date is that fire resistant trees become highly susceptible to being scarred by fires only when they have been scarred for the first time (Arno and Sneck 1977).

Calculations of mean fire intervals were then made as shown in table 2. (Median and maximum intervals were calculated from the same basic data.) For each sample unit, we listed all pre-1910 fire years recorded on any of the trees. The number of intervals between fires (one less than the number of fires) was then divided into the total number of years between the first and last fires. Part B (table 2) shows another approach we used to lengthen the fire record. These fire data are from an upper subalpine unit at Tolan, which had five fires between 1679 and 1811 (mean interval of 33 years) and none thereafter, although suppression did not begin until about 1910. We added the interval from the last fire until 1910 in this and other cases where its inclusion would lengthen the mean interval (adjusted mean interval 46 years). Although we do not know what the length of this final interval would have been had fire suppression not been started in 1910, we know that the interval would have been at least 99 years in this example case and that its addition should improve the estimate of the true mean.

Table 2.—A. Example of fire interval calculations for a small stand (at the Tolan Creek Study Area; upper subalpine slopes). All sample trees are lodgepole pine. (The 1932 cambium date for tree 17 coincides with a mountain pine beetle epidemic that also killed other fire-scarred trees in this area.)

Sample tree number				Composite fire scar chronology
13	16	17[1]	18	
Dates[2]				
1975c	1975c	1932c	1975c	
1871fs				1871
	1842fs			1842
1785fs	1785fs	1785fs	1785fs	1785
1757fs	1757fs		1757fs	1757
1752fs				1752
1648p	1648p		1664p	
		1632fs		1632
		1595fs		1595
		1526p		

Pre-1910 fire record: 1871 − 1595

mean fire interval = 276 years ÷ 6 fire intervals
= 46 years (range: 5-120 years)

B. Example of the approach used to lengthen the fire-interval record by adding the year 1910 (start of fire suppression) when its inclusion would lengthen the mean interval

	Composite fire scar chronology	
Added date	1910	
Mean interval 33 years	1811fs 1785fs 1752fs 1743fs 1679fs	Adjusted mean interval 46 years

[1]Snag
[2]c = cambium date; fs = fire scar date; p = pith date.

RESULTS AND DISCUSSION

Mean fire intervals were inversely related to size of the sample units. These relationships are shown for all three study areas in figure 3, A, B, and C, where each line represents mean fire intervals for different sizes of units within the same forest zone. The mean fire interval is shortest for large stands within any forest zone. (This overall statistic is actually the grand mean or mean of the mean fire intervals for all sample units of a given size by forest zone.) This mean fire interval for large stands is an estimate of the average number of years between fires (other than tiny spot fires) occurring within, but not necessarily spreading throughout, a given 200- to 800-acre (80-to 320-hectare) stand.

Conversely, the mean fire interval for any forest zone is generally longest when based on fire histories at points on the ground (grand mean from the individual trees with the most complete records). The grand mean fire interval is somewhat shorter when based upon combined fire records (mean fire interval) from each cluster of trees. This interval remained similar or was further reduced when based upon combined fire records from each grove and then from each small stand. A more consistent reduction in the fire interval occurs when the sample unit is enlarged to the large stand category.

A notable exception to these general trends occurs in the upper subalpine data at Tolan (fig. 3), where the single tree mean is shorter than those of the cluster and grove units. This results

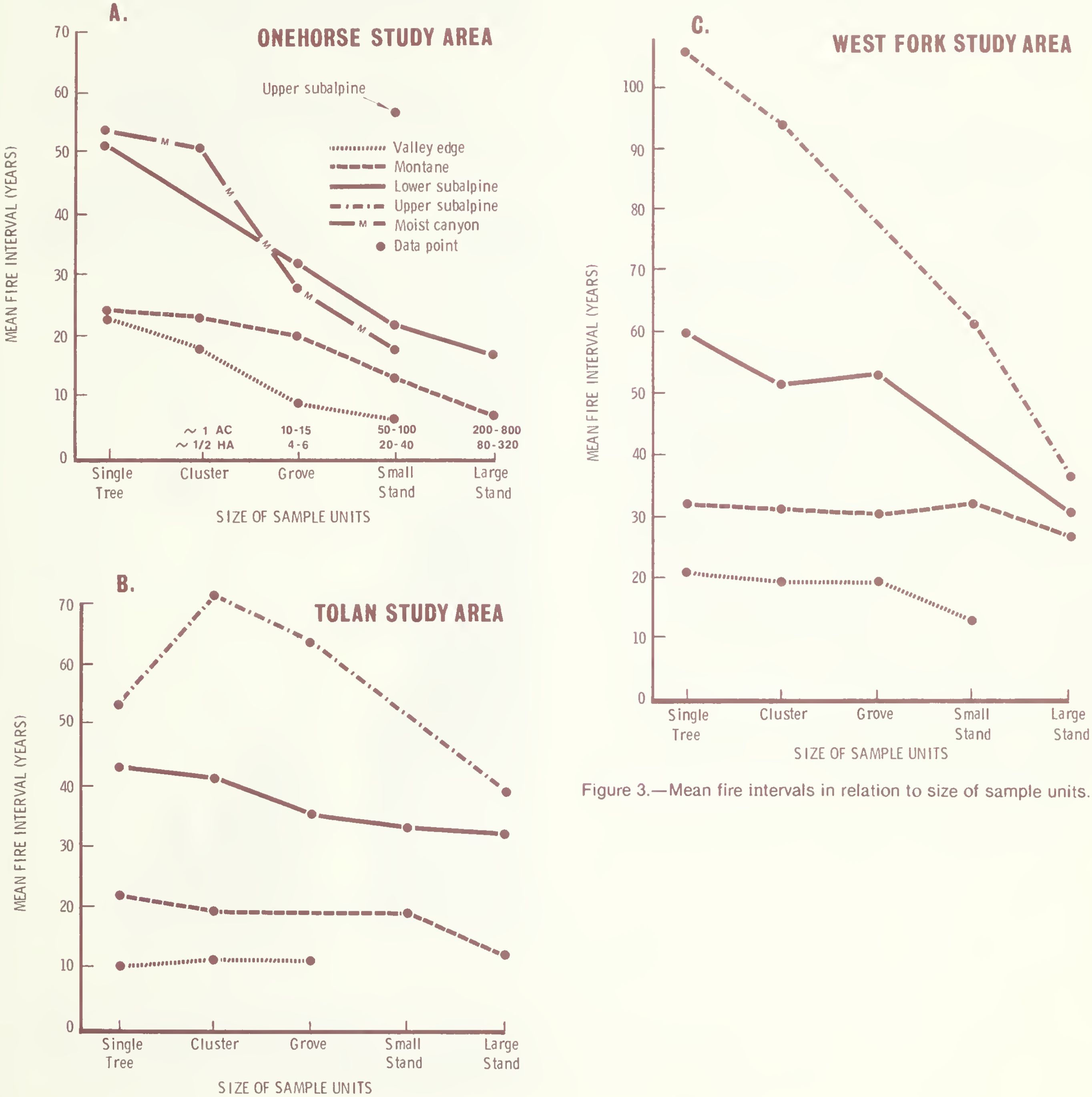

Figure 3.—Mean fire intervals in relation to size of sample units.

from shrinkage of the data base when the sample size is reduced from clusters to single trees. In this case, six **clusters** were available, but only four of them had an individual tree with more than one fire scar (table 3). A minimum of two fire scars is necessary for designating a fire interval on an individual tree. Thus, there was no means of estimating the fire interval for the two points on the ground probably having the longest intervals. This problem of defining fire intervals on individual trees, based on scars of at least two fires, would tend to be more critical in areas having long fire intervals. Prior to 1900, when wildland fires were seldom suppressed, fires undoubtedly burned incompletely and in a patchy pattern through many stands when weather or fuels were moist. Such fires would have scarred trees sporadically, as has occurred on some recent lightning fires that have been allowed to burn under surveillance in northern Idaho—for example, the 1979 Smith Mountain fire on the Kootenai National Forest (observed by Arno).

Table 4 presents median, mean, and maximum pre-1910 fire intervals for all size classes of sample units in each of the three study areas. Some of these mean intervals differ substantially from those listed in the earlier report (table 1) because of the additional stratification by sample-unit size and the effort to utilize the longest pre-1910 period of record as the basis for calculations. We feel that this new approach represents a significant refinement for potential users.

Table 3 lists the numbers of sample units by size class and forest zone. Some of the mean fire intervals were obviously based on small amounts of data. Still, the relatively consistent trends in the data seem significant.

In fact, these data probably reflect a **conservative** estimate of the effect of sample unit size on fire intervals. This conservatism occurs because spatial arrangement of our field samples (gathered long before this analysis was visualized) did not allow for a complete representation of consecutively enlarged sample units in the same locations. A more definitive examination of this effect could possibly be made using the data from several detailed fire history studies, such as Tande (1979), Heinselman (1973), Romme (1979), Davis (1980), and Madany and West (1980). Or, a new, detailed field study might be necessary, using an approach that would allow for analysis of progressively larger subsets of data and documentation of the effect of sample unit size on fire intervals. This would be a large undertaking if it were to apply to several forest zones or types.

Figure 4 compares mean fire intervals among the three study areas for the middle-sized grove (10 to 15 acres [4 to 6 hectares] sample unit) category. It is evident that the three areas had similar patterns of fire intervals in relation to forest zones. This and other data (table 4) show that fire intervals for a given forest zone were generally similar at Onehorse and Tolan, but usually somewhat longer at West Fork.[1] Overall, these findings illustrate the relatively frequent occurrence of fires in all forest zones, with the limited exception of the upper subalpine forest. As explained in Arno (1976), much of this pre-1910 fire occurred as surface fires that left a considerable amount of surviving overstory timber.

Figure 5 shows the distribution of fire intervals by interval length in small stands in the valley edge and montane zones at Onehorse. This skewed distribution is typical of these two forest zones, and it illustrates why the median fire interval for lower elevation forests is less than the mean at all three study areas (table 4). Also, this distribution emphasizes the unusualness of the maximum intervals reported in table 4. Strikingly, the number of years since the last fire in most units (except in the upper subalpine zone) is greater than the maximum fire intervals detected prior to 1910.

Table 3.—Number of sample units for the five size classes in each of three study areas on the Bitterroot National Forest. Data are presented by forest zone

Area and forest zone	Size class of sample units: Single tree	Cluster	Grove	Small stand	Large stand
ONEHORSE STUDY AREA					
Valley edge	3	2	2	1	-
Montane slopes	9	9	13	5	1
Moist canyon	2	2	3	1	-
Lower subalpine	2	-	3	2	1
Upper subalpine	-	-	-	1	-
TOLAN STUDY AREA					
Valley edge	1	1	1	-	-
Montane slopes	4	4	-	4	2
Lower subalpine	3	3	4	4	2
Upper subalpine	4	6	4	-	2
WEST FORK STUDY AREA					
Valley edge	1	1	1	1	-
Montane slopes	5	4	7	8	3
Lower subalpine	3	3	4	-	2
Upper subalpine	6	6	-	4	2

[1]A possible explanation for this is that the Onehorse area is immediately adjacent to the main Bitterroot Valley grassland where Indian-caused fire seem to have been frequent (Barrett 1981). Tolan and West Fork are more remote, but Tolan is a drier area where fuels may be receptive to burning during a longer season.

Table 4.—Median, mean, and maximum pre-1910 fire intervals for all size classes of sample units in each of three study areas on the Bitterroot National Forest. Findings are presented by forest zone. Median interval is in italics; mean is in bold type; maximum is in parenthesis

Area and Forest zone	Single tree (point on the ground)	Cluster (about 1 acre)			Grove (10-15 acres)			Small stand (50-100 acres)			Large stand (200-800 acres)		
ONEHORSE STUDY AREA													
Valley edge	**23**	*20*	**18**	(34)	*8*	**9**	(20)	*4*	**6**	(20)			
Montane slopes	**24**	*20*	**23**	(57)	*16*	**20**	(52)	*10*	**13**	(36)	*6*	**7**	(36)
Moist canyon	**54**	*50*	**51**	(71)	*30*	**28**	(51)	*15*	**18**	(33)			
Lower subalpine	**51**				*34*	**32**	(38)	*24*	**22**	(26)	*18*	**17**	(33)
Upper subalpine								*66*	**57**	(92)			
TOLAN STUDY AREA													
Valley edge	**11**	*11*	**12**	(30)	*11*	**12**	(30)						
Montane slopes	**23**	*20*	**20**	(41)				*19*	**20**	(50)	*10*	**13**	(38)
Lower subalpine	**44**	*44*	**42**	(50)	*36*	**36**	(54)	*33*	**34**	(56)	*30*	**33**	(63)
Upper subalpine	**54**	*69*	**72**	(102)	*56*	**64**	(103)				*40*	**40**	(71)
WEST FORK STUDY AREA													
Valley edge	**21**	*17*	**19**	(30)	*17*	**19**	(30)	*10*	**12**	(22)			
Montane slopes	**32**	*31*	**31**	(52)	*27*	**30**	(56)	*30*	**32**	(58)	*23*	**26**	(52)
Lower subalpine	**60**	*54*	**51**	(64)	*54*	**53**	(62)				*30*	**30**	(43)
Upper subalpine	**106**	*96*	**94**	(109)				*68*	**61**	(90)	*35*	**36**	(82)

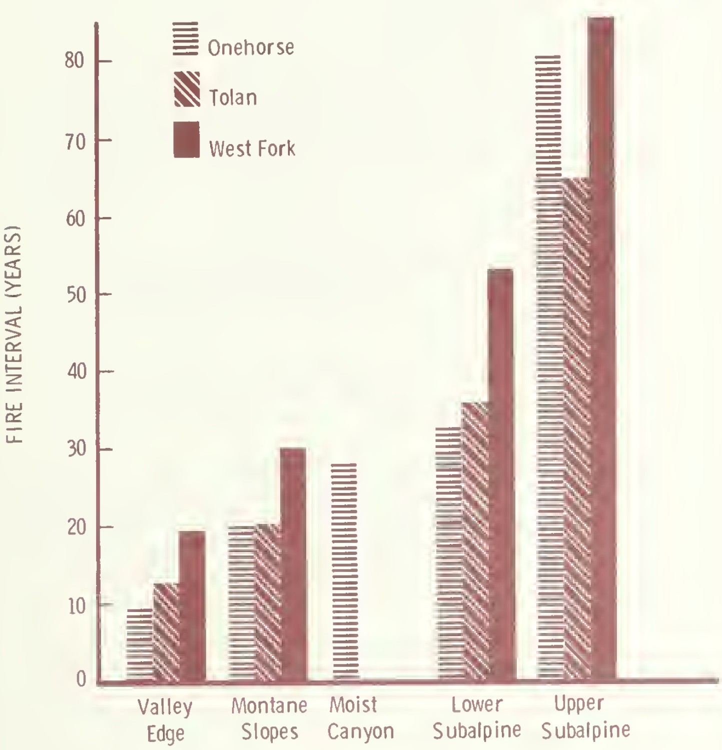

Figure 4.—Mean fire intervals in groves (10 to 15 acre sample units) for different forest zones in the three study areas.

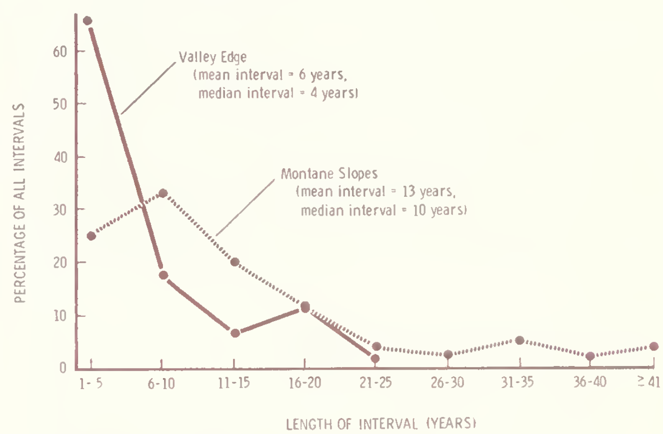

Figure 5.—Percentage distribution of fire intervals by interval length for small stands on the Valley Edge and Montane Slopes at Onehorse Study Area. The Valley Edge zone had 35 intervals in one small stand between 1668 and 1889. Montane Slopes had 133 fire intervals in 5 small stands between 1496 and 1904.

CONCLUSIONS

Recommendations for Fire History Research

It is apparent from this analysis that there are substantial variations in length of fire intervals related to sample unit size. The most reasonable approach when making comparisons is to use units of similar size and preferably those representing one of the intermediate categories—cluster, grove, or small stand. Units of these sizes allow adequate sampling intensity for detection of nearly all light surface fires, but are generally small enough to serve as a basis for site-specific fire history information. We suggest that in future studies the size of units be clearly specified and interpreted in comparisons to other studies. Smaller unit size (cluster, for example) may be desirable in types where trees (such as ponderosa pine or whitebark pine) are long-lived and readily fire scarred, whereas larger units (grove or small stand, for example) may be necessary for piecing together a more complete fire history in forest types where the oldest surviving trees are more scattered (for example, lodgepole pine) or more resistant to scarring (for example, western larch or Douglas-fir).

Fire History Implications on the Bitterroot National Forest

Study results show that the current long-term absence of fire contrasts strongly with pre-1900 fire intervals, especially in lower and middle-elevation forests. Lack of fire has allowed an undesirable buildup of dead and living (ladder) fuels in many stands, particularly in the ponderosa pine and Douglas-fir forests. It has also fostered chronic overstocking of unmerchantable trees, reducing tree vigor. Extensive buildups of dwarf mistletoe (*Arceuthobium douglasii*) in Douglas-fir and western budworm (*Choristoneura occidentalis*) in Douglas-fir, spruce, and true firs seem to be related to these changes in stand conditions (Fellin 1979). Certainly the pre-1900 fire regimen stimulated production of herbaceous or shrubby plants, useful as forage for wildlife and livestock. These are some reasons suggesting that reintroduction of fire under the right conditions could enhance values of various forest resources.

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The authors examine variation in the length of mean intervals between fires (occurring between the years 1600 and 1910) in sample units of various sizes, ranging from a point on the ground (single tree) to a large stand (200 to 800 acres; 80 to 320 hectares). Recommendations are made regarding appropriate sizes of sample units for fire history studies.

KEYWORDS: fire ecology, fire history, fire frequency, forest fire, forest ecology

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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